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EVIDENCE FOR PENNSYLVANIAN TRANSPRESSION FROM PRELIMINARY KINEMATIC FAULT ANALYSES IN THE SACRAMENTO MOUNTAINS, NEW MEXICO

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ABSTRACT.—Folds and faults in the western Sacramento Mountains are unconformably overlain by undeformed or weakly-deformed Permian strata, offering an excellent opportunity to study Pennsylvanian deformation related to Ancestral Rocky Mountains tectonics. Three major Pennsylvanian-Early Permian, north-south-striking faults in the range were chosen for detailed field study and kinematic analysis: the Fresnal, Alamo and Bug Scuffle faults. The faults studied here have been interpreted as either normal (Pray, 1959, 1961), vertical (Johnson, 1985), and, in the case of the Fresnal fault, normal with a dextral component (Cather, 2000) due to the obliquity of the fault with local fold axes. Slickensided minor faults (n = 588) were measured on and adjacent to these major faults. Eigenvector analysis of the slickenlines gives an average slip orientation of S72°W-37°. This average slip trend is 18 degrees from perpendicularity with the average fault strike, suggesting dextral oblique motion. Slickenlines measured on the major fault planes themselves (n = 56) are bimodal, with near vertical and near horizontal orientations. This indicates that both strike-slip and dip-slip motion occurred on the faults, perhaps in two separate events or during a partitioned transpressional event. These possibilities are being tested by more thorough kinematic analyses of fault and fracture data, construction of structural cross-sections and 3D models.

INTRODUCTION

The Sacramento Mountains form a sharp, west-facing escarpment on the eastern edge of the Tularosa Basin in south-central New Mexico. Strata in the Sacramento Mountains range in age from Precambrian to Cretaceous and have a total thickness up to 2440 m (Pray, 1961; Johnson, 1985). Paleozoic sedimentary rocks are well-exposed along the bulk of the escarpment and are also fairly well constrained in terms of deformational geometry. In general, structural features of the range can be classified into two groups: (1) late Cenozoic structures related to uplift of the range during basin-and-range block faulting that occurred throughout western North America and (2) structures that formed prior to uplift of the range (Pray, 1959, 1961; Johnson, 1985). The Sacramento Mountains are an excellent location to study Pennsylvanian deformation related to generation of the Ancestral Rocky Mountains because several well-exposed Pennsylvanian to early Permian (earliest Wolfcampian) faults and folds are unconformably overlain by undeformed or weakly-deformed Permian (mid-Wolfcampian to Guadalupian) strata.

Existing tectonic hypotheses for Ancestral Rocky Mountain formation predict conflicting shortening and compression directions as well as different fault kinematics. Formation related to the Ouachita-Marathon orogen (Kluth and Coney, 1981; Kluth, 1986) predicts northwest-southeast shortening and compression, whereas formation related to a possible Andean-type margin to the southwest predicts northeast-southwest shortening and compression (Ye et al., 1996). Left-lateral slip along north-striking faults would support the Ouachita-Marathon hypothesis, and right-lateral movement on the same faults would suggest compression from the southwest. The conflicting hypotheses of Kluth (1986) and Ye et al. (1996) were based primarily upon examination of sedimentary thickness and facies relationships between Ancestral Rockies basins in order to interpret timing and rate of tectonism in the region. The three faults studied here strike north-south for most of their extent and therefore offer an opportunity to test these hypotheses of Ancestral Rocky Mountain formation using structural controls (Fig. 1).

Three major, north-south-trending faults and their related folds were chosen for this study: the Fresnal, Alamo and Bug Scuffle faults (Fig. 1B). These faults are well exposed and are locally overlain by undeformed or weakly-deformed Permian strata (Pray, 1961). Minor fault data including shear sense (if evident) and slickenline and fault plane orientations were collected for kinematic analyses. The same data were collected along the major fault planes where exposed. Slickenlines were not well preserved for the most part, with more measured adjacent to the Fresnal (n = 405) than adjacent to either of the other two faults (n = 157 combined). Calcite growth fibers were preserved more often than siliceous slickenlines and proved to be the most definitive when determining slip sense in the field.

To date, preliminary analyses of fault data have been completed. Additional fault analyses, construction of structural cross-sections and eventual generation of localized 3D models for critical areas at fault bends are being done. It is hoped that these analyses will contribute to the understanding of late Paleozoic fault kinematics in the Sacramento Mountains as well as to our understanding of Ancestral Rocky Mountain deformation.

PREVIOUS WORK

Previous work in the Sacramento Mountains concentrated primarily upon stratigraphy. Pray (1961) described the general stratigraphic and structural history of the Sacramento Mountains and published geologic maps of the area at a 1:31,680 scale. Pray (1961) noted that both the Alamo and Bug Scuffle faults change separation direction along strike. Pray (1961) interpreted these as high-angle scissors faults. Presence of two anomalous "half-domes" in lower Paleozoic strata separated laterally by approximately 1.6 km on the Bug Scuffle fault (Pray, 1961) suggest

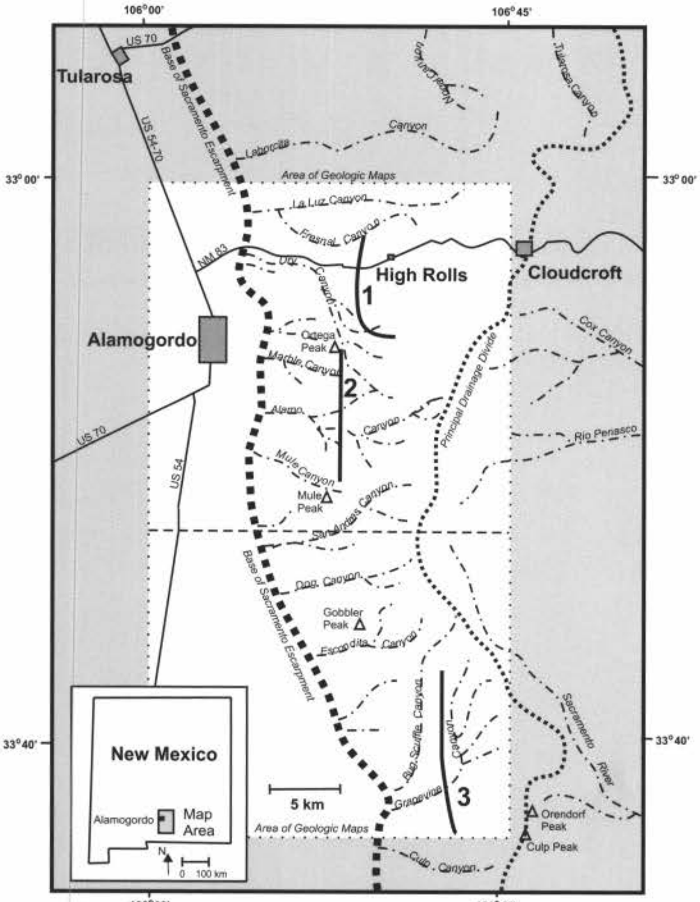

FIGURE 1. Location maps (adapted from Pray, 1961, fig. 2) showing A) the general location of the Sacramento Mountains near Alamogordo, New Mexico and B) the three Pennsylvanian- early Permian faults studied. Fault 1 - Fresnal Fault, Fault 2 - Alamo Fault, Fault 3 - Bug Scuffle Fault

right-lateral strike-slip displacement followed the folding that produced the dome. However, he concluded that "the available evidence of drag and a few slickenlines indicate dip-slip displacement" (Pray, 1961, p.130).

Stratigraphic separations along the Fresnal fault are on the order of 500 m (Pray, 1961). Pray (1961) interpreted this as a west-dipping normal fault and hypothesized that movement occurred at several times based on stratigraphic relationships. To explain the reversals of throw along the Alamo and Bug Scuffle faults, Pray (1961) suggested that scissors faults in the range were localized by lines of weakness in underlying Precambrian basement blocks.

In contrast, Johnson (1985) applied concepts of vertical tectonics and forced folding to the Sacramento Mountains. He compared the mechanical behavior of rock at low effective confining pressures to Pennsylvanian-Permian deformation in the Sacramento Mountains, known to have occurred under very shallow (300-1500 m) depth of burial. Strike continuity of structures is relatively poor in the Sacramento Mountains, which Johnson (1985) noted as characteristic of forced folded terranes where shape, size, and displacement of folds are controlled by presence of a forcing member below. He concluded that there was "no evidence of wrench faulting" and that "all faults have a dip-slip sense of motion" in the study area (Johnson, 1985, p.103). He used regional geometries to interpret solely dip-slip displacement on all faults and also attributed location of faults to geometry of inferred basement blocks. He concluded that vertical movement and lateral loading dominated the Pennsylvanian-Permian events in the Sacramento Mountains (Johnson, 1985).

Cather (2000) examined the Fresnal fault zone and observed roughly 500 m of stratigraphic separation along two strands of steeply (70°-85°) west-dipping normal faults with north-northeast strikes. Near the northern fork of Fresnal Canyon in the north of the study area, the western strand of the fault bends to the north-northwest and becomes a steep, east-dipping reverse fault (Cather, 2000). Oblique folding related to changes in fault strike in the northern portion of the fault and en echelon northwest plunging folds between and adjacent to the fault strand led Cather (2000) to suggest dextral slip along the Fresnal. Cather (2000) argued that principal episodes of deformation along the fault occurred in late Virgilian to early Wolfcampian time based on stratigraphic relationships. While multiple episodes of movement may have occurred along the fault, Cather (2000) indicated that the dextral component of slip was probably pre-mid Wolfcampian because the Early Permian Abo Formation buries the en echelon folds. Cather (2000) concluded that the Fresnal fault is a high-angle normal fault with localized reverse and dextral slip components.

METHODS

Two months of fieldwork were conducted in the Fall of 2001. Detailed mapping along the traces of the Fresnal, Alamo and Bug Scuffle faults included adjacent areas on either side of the fault traces where smaller faults and major folds were associated with the main faults. At each location, bedding and fracture plane strike and dip, and slickenline trend, plunge, and shear sense (if evident) were recorded. Fault plane orientations along the main fault planes were poorly preserved (n = 69) compared to other minor fault data (n = 519). This is attributed primarily to poor exposure of the actual main fault planes. Calcite growth fibers and Riedel fractures were used to determine shear sense (Petit, 1987). Calcite-growth fibers were the most abundant shear sense indicators, and Riedel fractures were scarce. Fault planes without slickenlines (n = 26) were identified by zones of cataclasis, or where different strata were present on either side of the plane. Additional fracture data (n = 1740) were also collected near all three major faults. These data include extensional joints as well as faults that lack slickenlines, cataclasis, or any distinct offset.

The slickenline and fault-plane data are being used to conduct kinematic analyses and to determine ideal compression axes directions using methods detailed by Erslev (2001). In this paper, preliminary kinematic analyses were performed on the entire fault dataset and on the subset of data collected on the major fault planes. In continuing work, the data will be divided into domains along the individual faults and analyzed in more detail. In addition, detailed map data collected during this study will be used to construct structural cross-sections and 3D models.

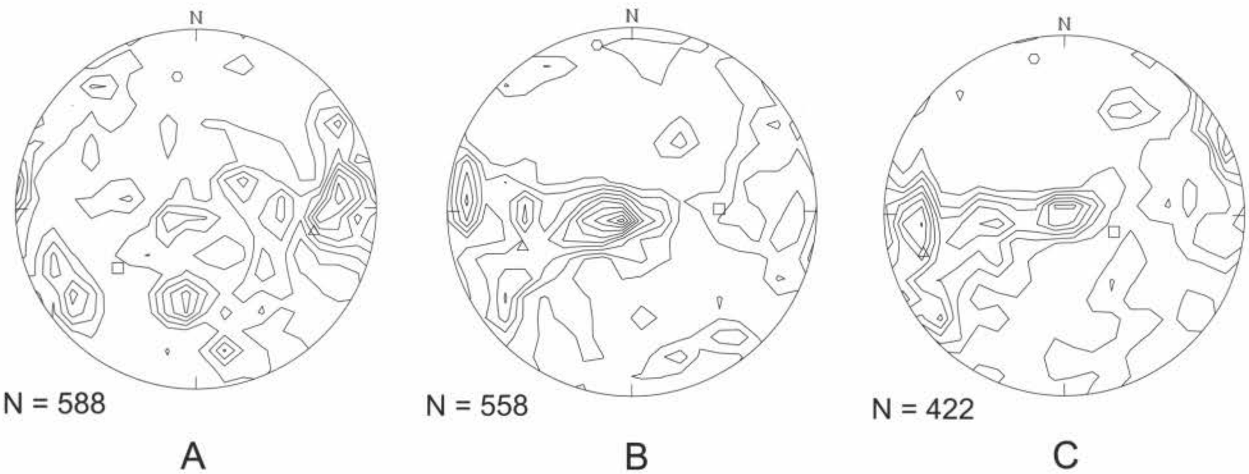

FIGURE 2. Stereonet plots of all minor fault data: Kamb method using 2% contours: A) poles to fault planes, B) slickenline lineations, C) ideal σ_1 axes.

PRELIMINARY RESULTS

Contoured stereonet plots of poles to fault planes, slickenline lineations and ideal σ_1 axes (25° from slickenlines using the method of Compton, 1966) were generated for all fault data (Fig. 2). Poles to fault planes (Fig. 2A) show a wide range of fault plane orientations, with the greatest concentration striking roughly north-south with a steep dip to the west. It is noted that lineations (n = 562) were present on only a portion of the faults that were measured (n = 588). Orientations of slickenline lineations (Fig. 2B) are multi-modal, with an average orientation of S72°W-37°. This mean lineation is the combination of three individual maxima oriented near-vertical, shallow to the west and shallow to the southwest (Fig. 2B). This average slip trend is 18 degrees from perpendicularity with the average fault strike, suggesting dextral oblique motion. The greatest concentration of lineations has an average trend and plunge of S70°W – 71°. These steep lineations represent dip-slip motion along the faults. The possibility that many of the fault planes have been rotated with bedding will be tested later by unfolding all the data. In addition to the steeply dipping slickenlines, there are a number of lineations showing a shallow to near-horizontal orientation (Fig. 2B). In general, the slickenlines define a N65°E-82°SE plane, suggesting slip along this plane, which is oblique to the main faults and nearly normal to the fold axes which trend approximately N10°W to N20°W.

Ideal σ_1 axes (Fig. 2C) define a N82°E-77°S best-fit plane. Both vertical and sub-horizontal compression directions are evident along this plane, indicated by a tight near-vertical maxima and diffuse east-west to northeast-southwest sub-horizontal maxima. This suggests dual-stage deformation in the study area. The pattern is similar to the bow-tie pattern of plotted compression axes noted by Erslev and Selvig (1997) in the Front Range of Colorado. Erslev and Selvig (1997) attributed this pattern to horizontal compression and variable amounts of horizontal axis rotations of early-formed slickenlines. For the Sacramento Mountains data, this pattern may support the hypothesis of Ye et al. (1996), suggesting that compression from the southwest generated the Ancestral Rockies.

A subset of measurements taken directly from the three main faults (n = 69) shows that the planes are oriented roughly north-south and most dip steeply to the west or are near vertical (Fig. 3), consistent with their mapped traces. A distinct bimodality of slickenline lineations is also evident (Fig. 3B). Most of the slickenline lineations trend east-west and range in plunge from near horizontal to near vertical. Most slickenlines within this group plunge steeply (n = 20), suggesting high-angle dip-slip movement along the faults. In addition, 10 slickenlines trend almost due north with shallow plunges. These are well-developed, major slickenlines on the fault planes indicating strike-slip movement along these faults. Shear sense was difficult to determine for these planes, with only one shear sense (right-lateral) recorded for the 10 planes.

CONCLUSIONS AND FUTURE WORK

In conclusion, this preliminary examination indicates both dip-slip and strike-slip movement occurred along the three major fault planes. The slight average obliquity of slickenlines to the major faults, and limited numbers of strike-slip slickenlines on the faults themselves, indicate a component of transpression but not a dominance of strike-slip motion. If there was a dominance of strike-slip motion, one might expect more north-south striking minor faults with strike slip.

Several factors will be considered with further fault analyses. Motion on the faults may have occurred in two separate events or during a partitioned transpressional event. In a partitioned event, alternating horizontal shortening and strike-slip motion could generate both high and low angle slickenlines in a single event as the faults weakened and the structures developed. Reactivation of pre-existing basement weaknesses may also explain the obliquity of slip direction to the stress field. Additional analyses of all minor fault data will compare the in situ data to data for which bedding rotations have been restored to determine the overall effects, if any, of rotations on shear sense and stress direction interpretations. Structural cross-sections and 3D models will incorporate the kinematic conclusions from the fault data as a further test of

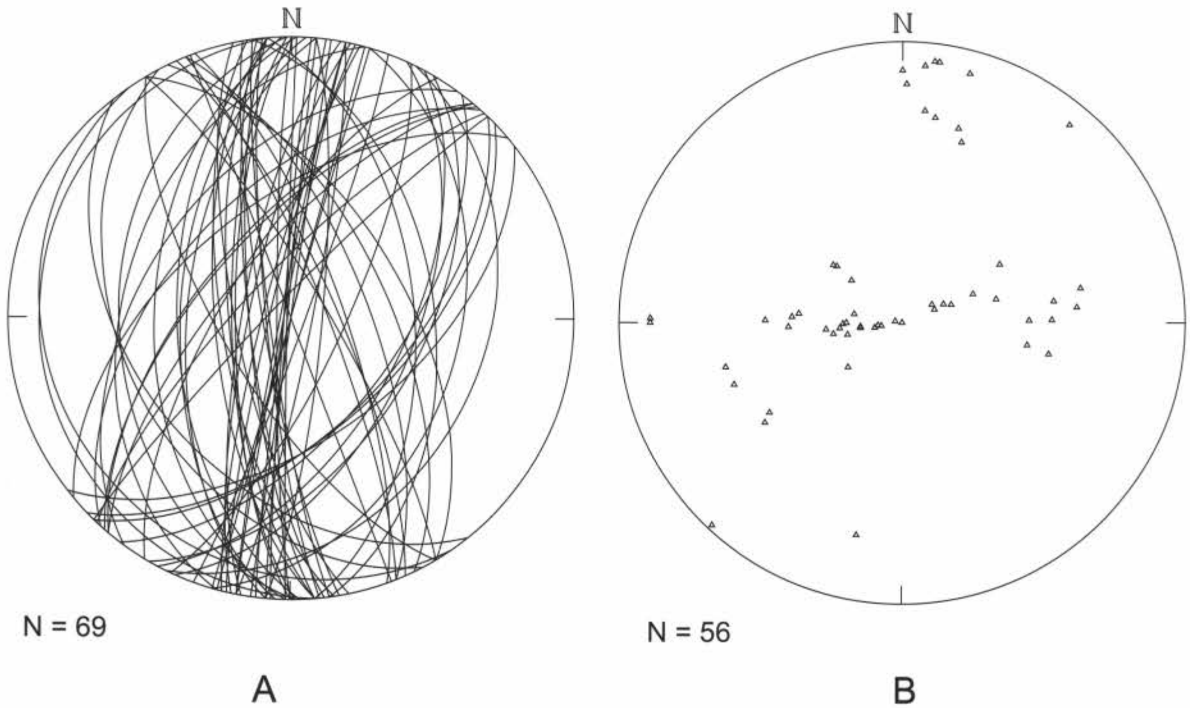

FIGURE 3. Measurements on major fault planes: A) fault planes, B) slickenline lineations.

kinematic hypotheses for both the Sacramento Mountains and the Ancestral Rocky Mountains as a whole.

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REFERENCES

Cather, S. M., 2000, Kinematics and timing of Ancestral Rocky Mountain faulting: Geological Society of America, Abstracts with Programs, 2000, p. A-465.

Compton, R.R., 1966, Analyses of Pliocene-Pleistocene deformation and stresses in northern Santa Lucia Range, California: Geological Society of America Bulletin, v. 77, p. 1361- 1380.

Erslev, E.A. 2001, Multi-stage, multi-directional Tertiary shortening and compression in north-central New Mexico: Geological Society of America Bulletin, v. 113, p. 63-74.

Erslev, E.A., and Selvig, B., 1997, Thrusts, backthrusts and triangle zones: Laramide deformation in the northeastern margin of the Colorado Front Range; *in* Bolyard, D.W., and Sonnenberg, S.A., eds., Geologic history of the Colorado Front Range: Denver, Rocky Mountain Association of Geologists, p. 65-76.

Johnson, M.R., 1985, Pennsylvanian-Permian deformation at 1,000-5,000 feet of overburden, Sacramento Mountains, New Mexico [M.S. Thesis]: College Station, Texas A&M University, 116 p.

Kluth, C.F. and P. J. Coney, 1981, Plate tectonics of the Ancestral Rocky Mountains: Geology, v. 9, p. 10-15.

Kluth, C.F., 1986, Plate tectonics of the Ancestral Rocky Mountains: Paleotectonics and sedimentation in the Rocky Mountain region, U.S.: American Association of Petroleum Geologists, Memoir 41, p. 353-369.

Petit, J.P., 1987, Criteria for the sense of movement on fault surfaces in brittle rocks: Journal of Structural Geology, v. 9, p. 597-608.

Pray, L. C., 1959, Stratigraphic and Structural Features of the Sacramento Mountain Escarpment; *in* Pray, L. C., ed., Guidebook for Joint Field Conference in the Sacramento Mountains of Otero County, New Mexico, sponsored by the Permian Basin Section Society of Economic Paleontologists and Mineralogists and the Roswell Geological Society, p. 86-130.

Pray, L. C., 1961, Geology of the Sacramento Mountains escarpment, Otero County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 35, 144p.

Ye, H., Royden, L., Burchfiel, C. and M. Schuepbach, 1996, Late Paleozoic deformation of interior North America: The greater Ancestral Rocky Mountains: American Association of Petroleum Geologists Bulletin, v. 80, p. 1397-1432.